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International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

1994

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PERFORMANCE TESTING OF A SEMI-HERMETIC COMPRESSOR WITH HFC-236ea AND CFC-114 AT CHILLER CONDITIONS

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ABSTRACT

HFC-236ea is one of the strongest candidates for a CFC-114 alternative in surface craft and submarine chillers. An earlier thermodynamic evaluation of the available alternatives resulted in the selection of HFC-236ea as the primary replacement candidate with coefficient of performance and volumetric capacity closest to those of CFC-114. A preliminary performance evaluation of HFC-236ea at 40°F (4.4°C) evaporating and 105°F (40.6°C) condensing temperatures in an oil-free compressor was performed in mid-1993 with promising results when compared to CFC-114 performance at the same conditions. Some material compatibility and oil miscibility work has also been performed with HFC-236ea in support of its use as a refrigerant. Building on these earlier works, this paper presents more comprehensive experimental test results for HFC-236ea in a compressor calorimeter using a semi-hermetic compressor.

In this study both HFC-236ea and CFC-114 were tested at a range of temperatures covering chiller conditions. Evaporating temperatures ranged from 35°F (1.7°C) to 55°F (12.8°C), and condensing temperatures ranged from 105°F (40.6°C) to 150°F (65.6°C) in order to develop a nine point test map. Polyol ester oil was used with the refrigerants. The following parameters were evaluated during the tests: suction and discharge pressures, their difference and ratio, cooling capacity, electric power, energy efficiency ratio (coefficient of performance), electric current, and compressor volumetric and isentropic energy efficiency. Compressor discharge, motor winding, and oil temperatures were also monitored.

INTRODUCTION

Although the predominant refrigerant used in the United States in large centrifugal chillers has traditionally been CFC-11, there is a small but important use of CFC-114 in centrifugal chillers. Approximately 1000 CFC-114 chillers ranging in capacity from 125 to 350 refrigeration tons (440 to 1230 kW) are in use by the U.S. Navy in surface craft and submarines to provide chilled water for air conditioning and equipment cooling. CFC-114 is the refrigerant of choice for these shipboard applications because it meets the special requirements for this sophisticated application.

However, the production of CFC-114 will be discontinued on December 31, 1995 along with production of other fully halogenated chlorofluorocarbons as required by the Montreal Protocol Amendments and the U.S. Clean Air Act Amendments. Several new refrigerant chemicals were proposed by the Environmental Protection Agency's (EPA's) Air and Energy Engineering Research Laboratory (AEERL) as alternatives to CFC-114 based on having properties close to those of CFC-114.[1] One of them, HFC-236ea (1,1,1,2,3,3-hexafluoropropane), has been the subject of more intense theoretical and experimental evaluation as a CFC-114 alternative. Beyerlein et al.[2] presented a technical paper comparing the thermophysical properties of HFC-236ea and CFC-114. In addition, Smith et al.[3] presented information on additional properties of HFC-236ea which supports its potential as a CFC-114 alternative.

One technique for additional evaluation of an alternative refrigerant is a calorimeter test of both the original refrigerant and the proposed alternative refrigerant. This calorimeter test will suggest how the alternative refrigerant will perform in a certain compressor under actual operating conditions. Information on capacity and efficiency characteristics of the tested compressor is the output of such a test. This paper describes the calorimeter evaluation of HFC-236ea as a potential alternative to CFC-114 under shipboard chiller operating conditions.

TEST EQUIPMENT AND METHOD

The test rig consists of a calorimeter and a semi-hermetic reciprocating compressor. The original purpose of the calorimeter was for testing compressors for low and medium temperature applications, primarily home refrigerator compressors. During initial operation with low pressure refrigerants, it became clear that the calorimeter as originally designed would not be useable with low pressure refrigerants because of the significant pressure drops in the refrigerant lines relative to their low absolute pressures. A number of calorimeter modifications reduced the effects of pressure drop. A water-cooled condenser was installed on top of the calorimeter to increase the liquid head pressure in the line. The refrigerant mass flow meter was removed because of its associated high pressure losses. The condenser water valve was removed since the pressure increase which was needed for activating the valve was too large relative to the absolute pressure and caused excessive condensing pressure and temperature fluctuations. Other arrangements were made to adjust and maintain condensing pressure. The original refrigerant lines were replaced with larger lines. Sight glasses were installed just before the expansion valve for monitoring the liquid feeding of the valve and on the suction line to watch for and prevent liquid refrigerant from overflowing from the evaporator into the compressor while setting the test conditions.

The compressor was designed especially for use with HFC refrigerants and polyol ester oils with materials compatible with both. The compressor was semi-hermetic with an air cooled 3/4 HP (0.56 kW) electric motor and a volumetric flow rate of 169 ft^3/hr (1.329 L/s) at 1750 RPM.

ASHRAE Standards 23-1978[4] and 23-1993[5] were used as a basis for developing the test method. Using this testing procedure, the cooling capacity was determined by a primary calorimeter method based on the heat required to maintain the temperature in the evaporator, and a secondary method based on the heat balance of the water cooled condenser. Tests were performed at 40°F (4.4°C) evaporating temperature and 105°F (40.6°C) condensing temperature to match the conditions of the Navy shipboard chillers. Tests were also performed at other condensing and evaporating temperatures around those baseline conditions to determine the sensitivity of the results to operating temperatures. Rather than having saturated vapor at the evaporator outlet (a typical operation for chillers), superheat of around 15°F (8.3°C) was maintained in order to prevent wet compression from occurring in the compressor. To compensate for the pressure drops in the liquid lines, which are relatively high for all low pressure refrigerants, the refrigerant was sufficiently subcooled in the condenser to achieve at least 5°F (2.8°C) subcooling at the expansion valve inlet. During evaluation of the test data, the test results were corrected back to the chiller saturated liquid and vapor conditions. Besides the parameters related to the performance of the compressor, six motor winding temperatures and the oil temperature at the sump bottom were also monitored as parameters affecting the lifetime and reliability of the compressor. The compressor isentropic efficiency and volumetric efficiency were determined using equations derived in an earlier work.[6]

RESULTS OF CALORIMETER TESTS AND INTERPRETATION OF TEST RESULTS

The results of calorimeter testing of CFC-114 over a range of evaporating temperatures from 35°F (1.7°C) to 55°F (12.8°C) and condensing temperatures from 105°F (40.6°C) to 150°F (65.6°C) are shown in Figures 1 (energy efficiency ratio) and 2 (cooling capacity). Results of similar testing of HFC-236ea are shown in Figures 3 and 4. Figures 5 and 6 show the ratios of these values for HFC-236ea relative to CFC-114. The compressor isentropic efficiency and volumetric efficiency characteristics for both refrigerants are shown in Figures 7 through 10. Figure 11 and 12 show the ratios of these efficiencies for HFC-236ea relative to CFC-114.

The energy efficiency ratio (EER) of HFC-236ea is very close to the EER of CFC-114. At the 105°F (40.6°C) condensing temperature and evaporating temperatures between 40°F (4.4°C) and 55°F (12.8°C) the difference between the values of HFC-236ea and CFC-114 is the same order of magnitude as the accuracy of the test method. However, at the condensing temperature of 150°F (65.6°C), which is not likely to occur at submarine and surface craft chiller conditions, the EER of HFC-236ea is lower than the EER for CFC-114 by a difference which is slightly greater than the error of the test method. In general, the conclusion is that, in terms of EER, HFC-236ea is a good match for CFC-114. This conclusion is in good agreement with the theoretical predictions resulting from the thermodynamic evaluation of HFC-236ea and CFC-114 in a vapor compression cycle at chiller conditions.[7]

The cooling capacity of HFC-236ea is somewhat lower than that of CFC-114. The difference is about 5 percent smaller at 105°F (40.6°C) condensing temperature and about 15 percent smaller at 150°F (65.5°C). These findings agree with the results from the thermodynamic evaluation.

Useful conclusions can be drawn for the compressor characteristics with HFC-236ea and CFC-114. The compressor isentropic efficiency with HFC-236ea is the same as with CFC-114 at 105°F (40.6°C) condensing temperature. At higher condensing temperatures the compressor isentropic efficiency with HFC-236ea tends to be less than with CFC-114. The compressor volumetric efficiency with HFC-236ea is about 5 to 10 percent lower than with CFC-114. This result was expected because of the higher pressure ratio (10 to 20 percent) for HFC-236ea.

During the whole testing period, the compressor has been operating for approximately 1800 hours. No abnormal behavior of any part of the test rig was observed. The compressor, charged with the polyol ester oil, worked reliably in consecutive order with CFC-114 and HFC-236ea. The winding temperatures at the six locations of the compressor motor and the oil temperature at the sump were within acceptable limits for both refrigerants in the whole range of test conditions. This suggests that no temperature related durability and lifetime problems are to be expected.

CONCLUSIONS

1. Calorimeter tests confirm the theoretical conclusions from the earlier thermodynamic evaluations that HFC-236ea is a viable replacement for CFC-114.

2. At chiller conditions (105°F condensing temperature), the energy efficiency ratio and compressor isentropic efficiency with HFC-236ea are very close (within experimental error) to those of CFC-114 over the range of evaporating temperatures. At the same conditions, the cooling capacity of HFC-236ea and the compressor volumetric efficiency are 2 to 7 percent lower than those of CFC-114.

3. During 1800 hours of testing with the two refrigerants, the semi-hermetic compressor charged with polyol ester oil performed reliably. The temperature level of the compressor in terms of discharge, windings, and oil temperatures was within acceptable limits for both refrigerants.

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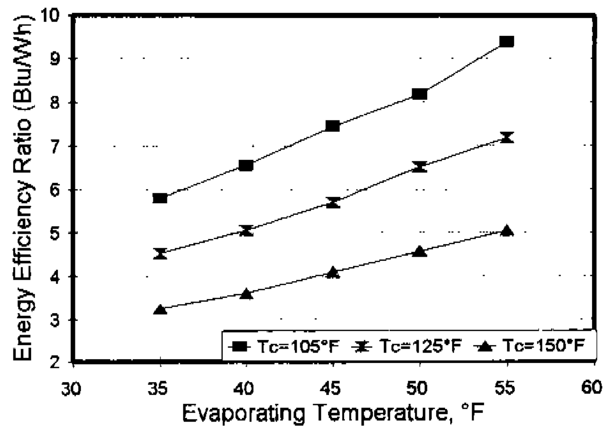

Fig. 1: EER for CFC-114

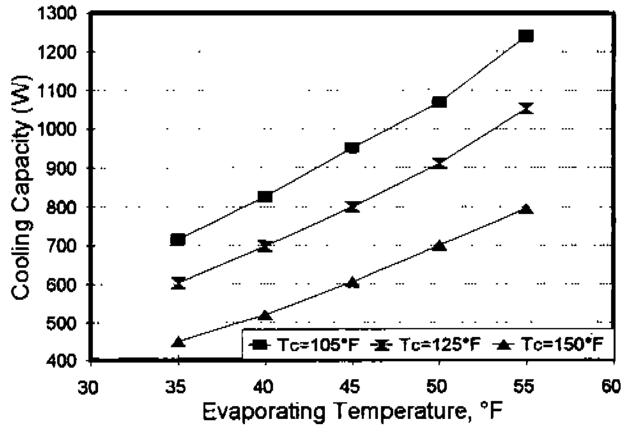

Fig. 2: Cooling Capacity for CFC-114

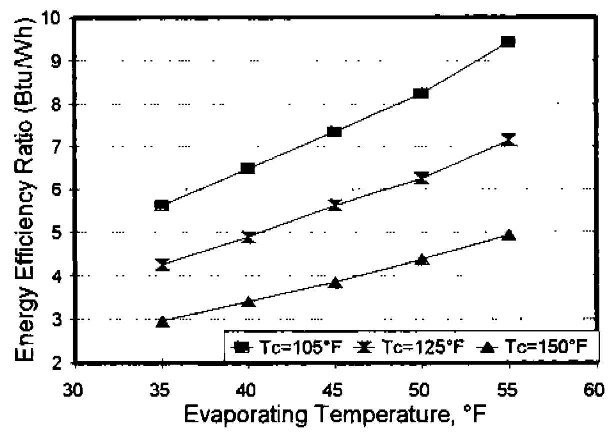

Fig. 3: EER for HFC-236ea

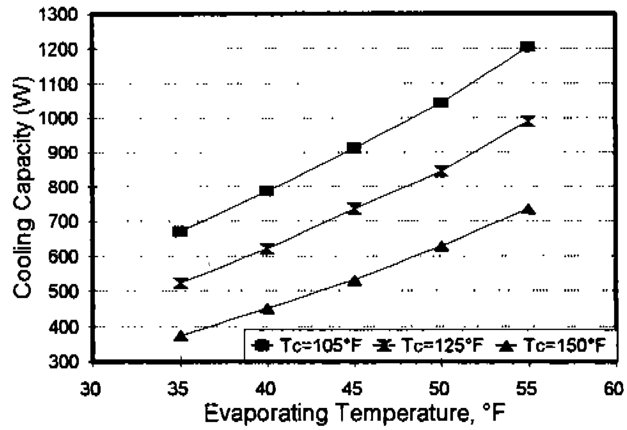

Fig. 4: Cooling Capacity for HFC-236ea

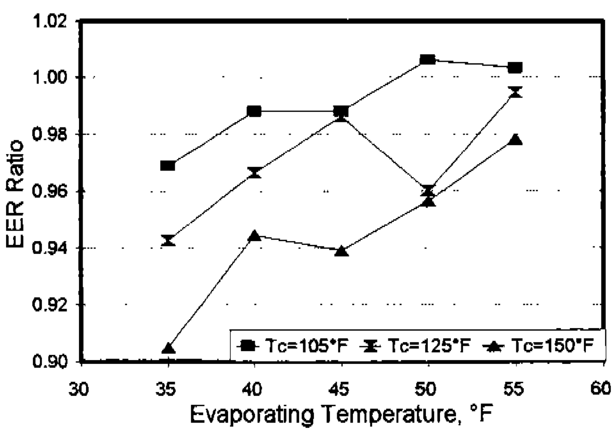

Fig. 5: EER Ratio of HFC-236ea to CFC-114

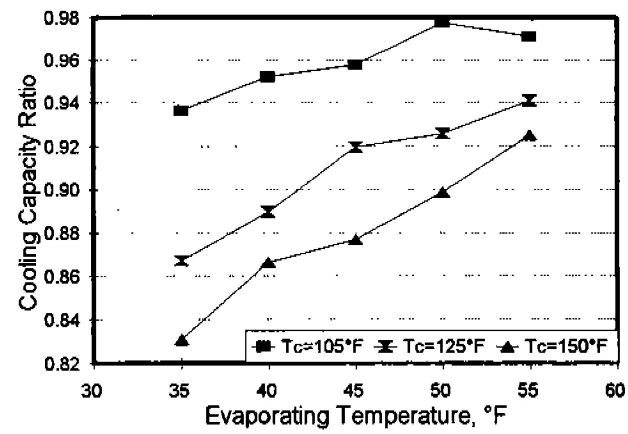

Fig. 6: Capacity of HFC-236ea to CFC-114

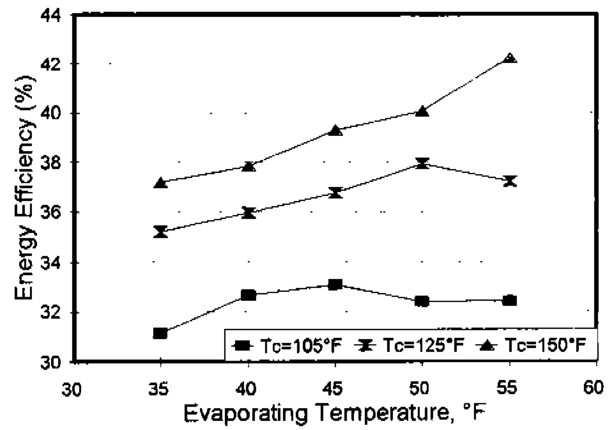

Fig. 7: Compressor Efficiency for CFC-114

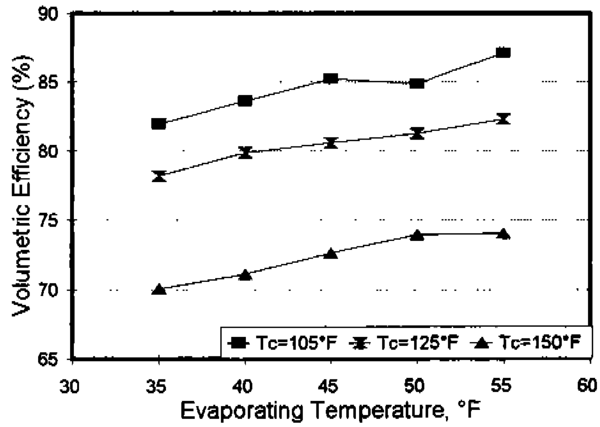

Fig. 8: Volumetric Efficiency for CFC-114

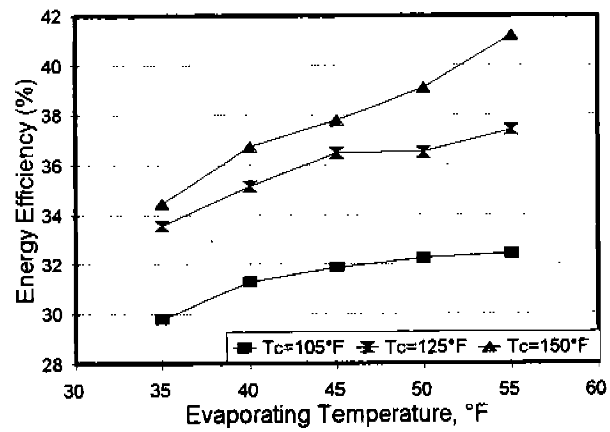

Fig. 9: Compressor Efficiency for HFC-236ea

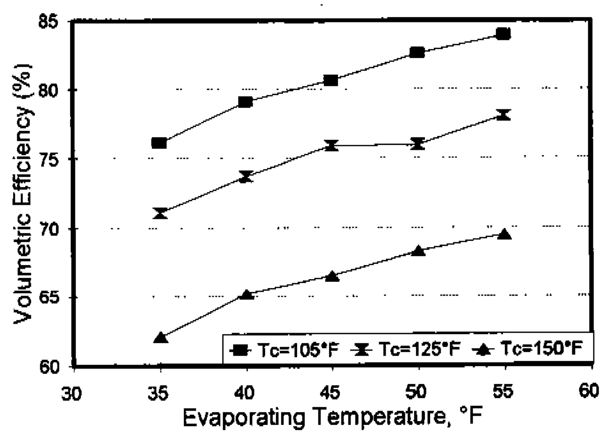

Fig. 10: Volumetric Efficiency for HFC-236ea

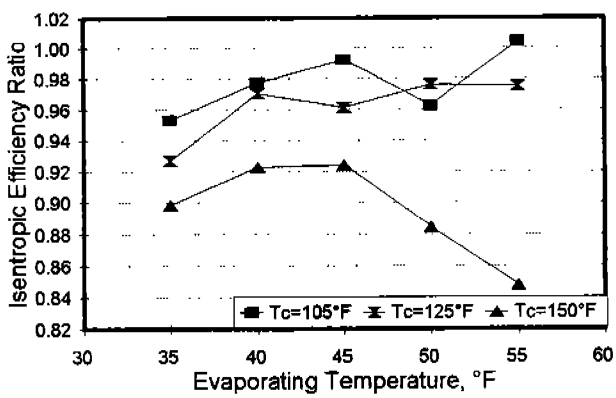

Fig. 11: Compressor Isentropic Efficiency Ratio of HFC-236ea to CFC-114

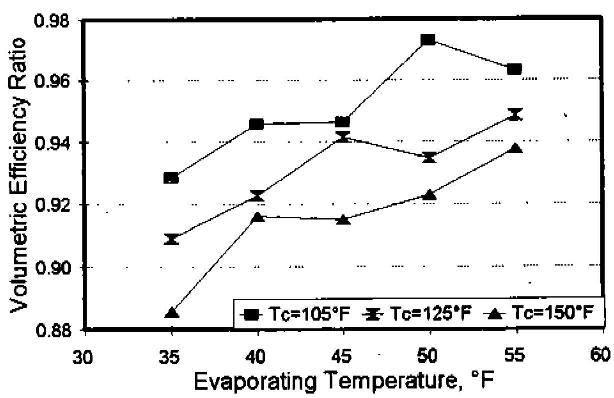

Fig. 12: Compressor Volumetric Efficiency Ratio of HFC-236ea to CFC-114